Determination of the Helios Spacecraft Attitude by Polarization Measurement

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The possibility of determining the attitude or orientation of the Helios spacecraft by means of polarization measurements of the spacecraft radio signal is described. One principal error source is the Faraday rotation of the S-band radio signal by Earth's ionosphere. If this effect can be removed by independent measurements of the ionosphere, then the orientation of the spacecraft in two dimensions perpendicular to the spacecraft line-of-sight can be determined to better than 0.5 deg.

The Helios spacecraft is required to point certain instruments in the direction of the sun. A problem arises in that the spacecraft orientation in space cannot be determined if a Canopus sensor is not incorporated in the spacecraft system. An alternative to determining the orientation in two dimensions perpendicular to the line-of-sight of the spacecraft would be to measure the polarization angle of the linearly polarized S-band signal transmitted by the spacecraft. One major problem in this approach is the effect of Earth's ionosphere. As the signal passes through the ionosphere, the polarization angle is rotated by the Faraday effect. This rotation amounts to several degrees, depending on the density of electrons in the ionosphere and the elevation angle of the spacecraft.

To remove this error source, a possible solution is to make independent measurements of Earth's ionosphere (e.g., from ATS-1, a geostationary satellite, by Faraday rotation at VHF). These measurements can then be mapped to the line-of-sight of the Helios spacecraft by techniques described in Ref. 1.

Figures 1 and 2 present two typical comparisons. The upper graph shows the Pioneer data (designated •) in terms of total electron content (TEC) and the mapped satellite data (designated □). The lower graph shows the difference between the Pioneer and the satellite (Pioneer data minus satellite data). From these two figures, one can see that, for higher elevation angles near meridian transit, the comparisons are quite good. However, at rise or at set, the two curves tend to diverge widely. This is most likely due to the breakdown of the assumption of a reference point at a constant altitude to facilitate computation of Earth's magnetic field vector along the ray-path. On some days, the Pioneer data were so noisy that no calculation was attempted. In the case of Pioneer 9, some of the noise could have been due to solar coronal effects. Disturbances in Earth's ionosphere could also introduce noise in either the Pioneer 6 or 9 data.

Figure 3 shows the difference in polarization angle between the Pioneer and the rotation predicted by mapping the satellite data to the Pioneer line-of-sight. The Pioneer polarization angle measurement occasionally dropped below 90 deg, which may be due to equipment problems or, more likely, misorientation of the Pioneer spin axis. It cannot have been caused by Earth's ionosphere (though the solar corona can produce such an effect). Note that Pioneer 9 has a slight positive bias, while Pioneer 6 has a smaller negative bias. These biases could be due to misalignment of the two spacecraft rotation axes to the ecliptic plane. Since the measurements were taken at about the same time, and are both east and west of the tracking station, it is not likely that the biases are the result of errors in mapping.

The numbers used to produce Fig. 3 are tabulated in Table 1. The percentage error in the predicted polarization angle is generally less than 20%. If we agree to attribute the constant or the bias error to spacecraft orientation, then the error would be 0.3 deg or smaller (1 sigma).

The Pioneer orientation can vary slowly over one spacecraft revolution about the sun by about 1 to 1.5 deg.[1] The spacecraft should always return to its initial orientation at the end of the revolution. Consequently, over a period of a month, a small bias in orientation may be expected.

[1]Private communication from A. J. Siegmeth, JPL.

In conclusion, the orientation of a spacecraft can be determined to a few tenths of a degree by making S-band polarization measurements if the spacecraft maintained its attitude for weeks at a time, and if the polarization measurements can be accumulated and averaged over several days. This is assuming that the spacecraft is not near solar occultation, at which time the solar corona effects would overwhelm any attempt at using this technique.

Individual passes might be adequate. However, the possibility of ionospheric storms would indicate that data for several days should be accumulated so that the technique could be applied under quiet ionospheric conditions.

Acknowledgment

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Reference

1. Mulhall, B. D., *User's Guide to Ionospheric Comparison Program,* JPL Internal Document TM 391-380, Jet Propulsion Laboratory, Pasadena, Calif., Oct. 25, 1972.

Table 1. Pioneer line-of-sight data

Date M D Y	UT, h	TEC[a], 10^{17} m^{-2}	Error, 10^{17} m^{-2}	Polarization[b], deg	Error, deg	Error, %	Pioneer elevation[c], deg	Pioneer azimuth[c], deg
Pioneer 6								
11 04 70	1.8	6.2	−0.28	3.3	−0.15	4.5	25.8	210
05	1.7	5.1	−0.58	2.5	−0.28	11.4	26.5	209
08	Not usable							
09	Not usable							
10	1.6	2.9	−0.65	0.8	−0.18	22.4	28.4	206
11	1.4	3.4	−1.4	1.2	−0.50	41.2	29.7	203
12	Not usable—large trends in differences							
14	1.4	3.8	−0.49	1.6	−0.21	12.9	30.2	203
16	Not usable							
18	Not usable—large trends in differences							
21	1.4	2.4	−0.26	0.4	−0.04	10.8	32.4	202
	Average polarization error = −0.23 deg, standard deviation = 0.16 deg							
Pioneer 6								
12 10 70	1.5	2.2	−0.22	0.1	−0.01	12.3	38.8	202
11	Not usable							
12	1.8	1.2	−0.02	−0.07[d]	−0.001	16.3	38.2	207
14	Not usable							
24	1.0	0.9	−0.40	−0.21[d]	−0.094	44.5	46.2	194
	Average polarization error = −0.035 deg, standard deviation = 0.052 deg							
Pioneer 9								
10 04 70	Not usable							
06	Not usable							
07	Not usable							
10	Not usable							
11	Not usable							
13	21.8	7.97	0.796	4.5	0.45	10.0	31.4	242
14	22.2	9.63	1.00	5.3	0.55	10.4	27.7	245
15	Not usable							
17	16.7	8.43	1.47	5.6	0.98	17.4	43.0	140
18	16.4	5.28	0.3	2.6	0.15	5.7	39.5	134
20	16.0	4.74	0.57	2.0	0.24	12.0	35.4	129
21	19.8	5.83	0.27	3.9	0.18	4.6	46.3	205
	Average polarization error = 0.425 deg, standard deviation = 0.314 deg							

[a]Total electron content, 10^{17} electrons/m^2.

[b]Modulus 90 deg with respect to the ecliptic.

[c]ATS-1 viewed from Stanford University is at El = 37.2 deg, Az = 222.2 deg.

[d]Negative polarization angles cannot be due to the ionosphere for the geometry of this experiment.

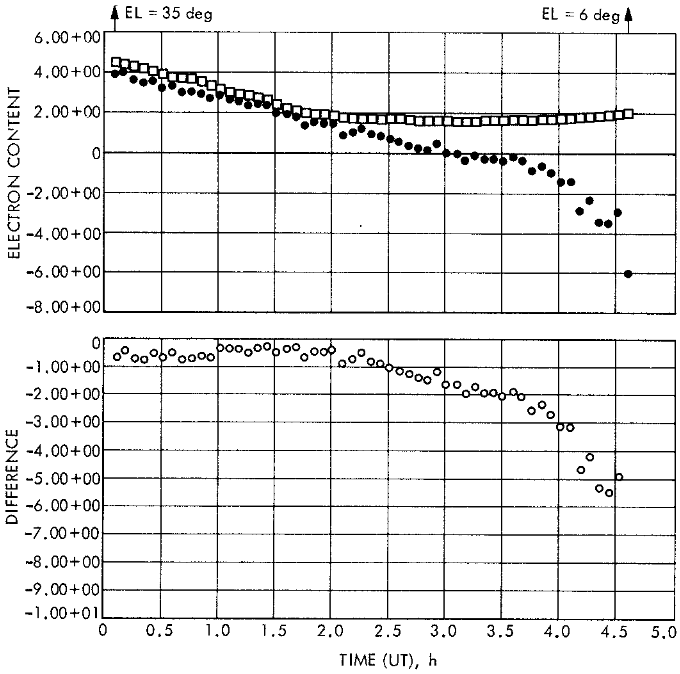

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Fig. 1. Pioneer 6 signal polarization

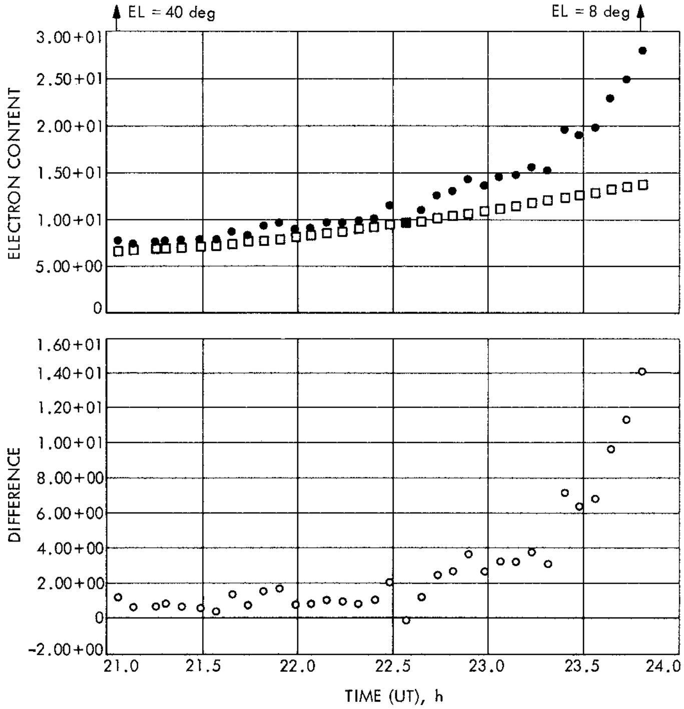

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Fig. 2. Pioneer 9 signal polarization

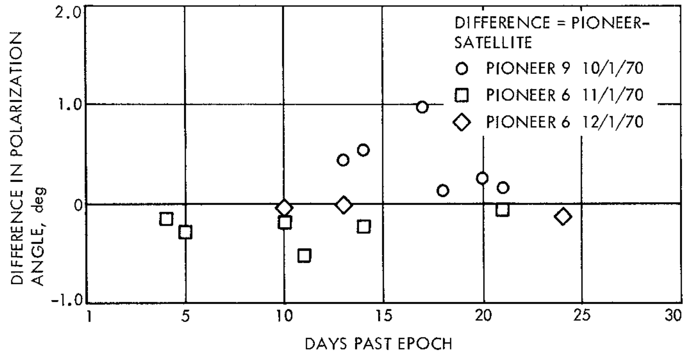

Fig. 3. Pioneer polarization angle differences